

Rapid Urbanization over Gazipur District of Bangladesh: Impact Assessment on Forests and Local Climate Using Multispectral Remote Sensing Data

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Abstract

Globally, the urbanization causes land use change and it results in decreasing the vegetation cover and increasing the Land Surface Temperature (LST). So the balance of environment is being destroyed. In this research, change of Land Use and Land Cover (LULC), Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) of the Gazipur District, Bangladesh from 2000 to 2021 were identified by analyzing Landsat 5 and Landsat 8 imageries with Google Earth Engine and ArcGIS tool. The results showed that deep forest area, water bodies and agricultural land were reduced from 14.48% to 10.13%, from 15.35% to 13.21% and from 25.54% to 21.1%, respectively. Light forest area and built-up area were increased from 40% to 47.18% and 4.58% to 8.4%, respectively, within the timeframe. Average NDVI was increased from 0.350 to 0.576. However, average minimum LST was increased by 1.044°C, average maximum LST was increased by 2.498°C and average mean LST was increased by 1.014°C from 2000 to 2021. The results showed a significant relationship between the growth of urban built-up and rising LST. Upazila with the most urban expansion, such as Sreepur and Kaliakair, exhibited the highest LST increases. A strong correlation was found between built-up area changes and maximum temperature ($r = 0.98$), and a moderate correlation with mean temperature ($r = 0.72$), highlighting the impact of urbanization on local temperature extremes. This research can help conserve the forest land, water bodies and agricultural land and facilitate the policy makers in sustainable and climate friendly city planning in Bangladesh.

Keywords: *Land Use and Land Cover Change (LULC), Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI)*

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সারসর্ম: বিশ্বব্যাপী নগরায়ন ভূমির ব্যবহারকে পরিবর্তন করে, যার ফলে গাছপালার পরিমাণ হ্রাস পায় এবং ভূমিষ্ণু তাপমাত্রা বৃদ্ধি পায়। এতে পরিবেশের ভারসাম্য বিনষ্ট হয়। এই গবেষণা ল্যান্ডস্যাট-৫ এবং ল্যান্ডস্যাট-৮ থেকে গৃহীত ইমেজের মাধ্যমে ২০০০ ও ২০২১ এর মধ্যে বাংলাদেশের গাজিপুর জেলার ভূমির ব্যবহার ও ভূমির আচ্ছাদন, নরমালাইজড ডিফারেন্স ভেজিটেশন ইনডেক্স (এনডিভিআই) এবং ভূমিষ্ণু তাপমাত্রা (এলএসটি) পরিবর্তন নির্ধারণ করে। এতে গুপ্তল আর্থ ইনিজন ও আর্ক জিআইএস ব্যবহার করা হয়েছে। গবেষণায় দেখা গেছে গভীর বনাঞ্চল, জলাভূমি এবং কৃষিভূমি যথাক্রমে ১৪.৪৮%

থেকে ১০.১৩%, ১৫.৩৫% থেকে ১৩.২১% এবং ২৫.৫৪% থেকে ২১.১% হ্রাস পেয়েছে। অন্যদিকে, অবক্ষয়িত বন এবং নির্মিত এলাকা যথাক্রমে ৪০% থেকে ৪৭.১৮% এবং ৪.৫৮% থেকে ৮.৪% বৃদ্ধি পেয়েছে। গড় এনডিভিআই ০.৩৫০ থেকে ০.৫৭৬ বৃদ্ধি পেয়েছে। যাইহোক, ২০০০ থেকে ২০২১ পর্যন্ত গড় ন্যূনতম তাপমাত্রা ১.০৪৪°সে, গড় সর্বাধিক তাপমাত্রা ২.৪৯৮°সে এবং গড় তাপমাত্রা বৃদ্ধি পেয়েছে ১.০১৪°সে। গবেষণার ফলাফল শহুরে নির্মিত এলাকার বৃদ্ধি ও বৃদ্ধিপ্রাপ্ত এলএসটি এর সাথে একটি গুরুত্বপূর্ণ সম্পর্ক খুঁজে পায়। সবচেয়ে বেশী বৃদ্ধিপ্রাপ্ত শহুরে এলাকায়ুক্ত উপজেলা, বিশেষ করে শ্রীপুর ও কালিয়াকৈর এ এলএসটি সবচেয়ে বেশী বৃদ্ধি পেয়েছে। নির্মিত এলাকার পরিবর্তন এর সাথে সর্বাধিক তাপমাত্রার একটি শক্তিশালী পারস্পরিক সম্পর্ক ($r=0.98$), এবং গড় তাপমাত্রার সাথে একটি মাঝারি সম্পর্ক ($r=0.92$) পাওয়া গেছে। ফলে স্থানীয় চরম তাপমাত্রার সাথে নগরায়নের একটি প্রভাব পরিলক্ষিত হয়। এই গবেষণার ফলাফল বনভূমি, জলাভূমি এবং কৃষিভূমি সংরক্ষণে কাজে লাগবে এবং বাংলাদেশের টেকসই ও জলবায়ু সহায়ক নগর পরিকল্পনা সম্পর্কিত নীতি নির্ধারকদের সহযোগীতা করবে।

1. Introduction

Urbanization is one of the crucial causes of land use changes (LUC) in the third world countries in recent years. Natural vegetation area is being converted into disturbed vegetation area and then into built-up area by human activities [1]. Cities in many different countries are becoming warmer than their surroundings due to decreasing the water bodies and vegetation cover [2-4]. Concrete surfaces, air conditioning, and other heat-producing activities are the causes of urban heat island. Thus the cities are becoming Heat Islands [5-7].

As LULC causes changes in rainfall, temperature of air and soil surface, urbanization is changing the climate. Urbanization reduces the vegetation covers, water bodies, and agricultural lands thus the temperature of the earth is rising which result in global warming [8]. Globally, temperature of the earth surface is positively correlated with the urbanization [9].

As Bangladesh is densely populated country, urbanization is taking place rapidly. Forests are being cleared, factories are being set up on agricultural land around the cities, new riverbeds are being encroached upon in Bangladesh [10]. In Bangladesh, different development activities are taking place relentlessly, i.e., bridge construction, expressway construction, railway line and station construction, new universities establishment, sea-port and airport establishment, rehabilitation project, etc. Every man-made activities create a particular range of radiation and result in concentrated radiated zone [6]. Population growth and economic development caused a huge urbanization by encroaching surrounding vegetation covered hilly areas of the Chattogram City in Bangladesh [11]. Urbanization changes the heat or energy budget which increase the Land Surface Temperature (LST). For example, LST increased

by 0.15°C in Winter and 0.24°C in Summer per year in Chattogram city, Bangladesh from 1993 to 2000 [12].

Previously, Hassan and Nazem [11], and Imran et al. [12] for Chattogram City; Dewan and Yamaguchi [13], and Imran et al. [14] for Dhaka city studied the LULC. Rafa et al. [15], Patwary and Rahman [16], Nath [17] and Shahidul Islam et al. [18] studied on NDVI of Sitakunda Botanical Garden and Eco-park in Chattogram, Dhaka City, Bandarban Hill Tracts and Chittagong Hill Tracts in Bangladesh, respectively. And Abir et al. [19], Hasnat [20], Imran et al. [12], Imran et al. [14], Shahidul Islam et al. [18] studied on LST of Bogura, Dudpukuria-Dhopachari Wildlife Sanctuary, Chattogram City, Dhaka City and Chittagong Hill Tracts in Bangladesh. However, there is a knowledge gap of LULC, NDVI and LST in Gazipur district of Bangladesh.

Urbanization is increasing by converting the vegetation cover, water bodies, hilly area, and agricultural land into built-up area in Bangladesh. Thus, the land use and land cover is changing [10, 11, 13]. In most of the areas, the Normalized Difference Vegetation Index (NDVI) is decreasing that means the vegetation covers is decreasing. However, in some regions, vegetation cover is increasing due to proper management [21, 22]. The growing urban and transportation areas, the burning of fossil fuels in various industries, the reduction of vegetation cover, the alteration in cropping practices, and other factors are all contributing to the daily rise in LST [23, 24]. Mean LST has increased by 0.62°C in the last 20 years in Bogura, Bangladesh [19], 7.7°C from 1990 to 2020 in Dudpukuria-Dhopachari Wildlife Sanctuary, Bangladesh [20], 0.15°C (in Winter) and 0.24°C (in Summer) per year from 1993 to 2020 in Chattogram City, Bangladesh [12], 0.24°C per year from 1993 to 2020 in Dhaka City Bangladesh [14]. The research question of this study was: “Is there any changes in LULC, NDVI and LST in Gazipur district between 2000 and 2021?” The study hypothesized that within the timeframe from 2000 to 2021, Gazipur district gained substantial urbanization and experienced a temperature increase. With this hypothesis, the study was undertaken to identify the changes of LULC, NDVI and LST in Gazipur district between 2000 to 2021. The findings of the study will be useful to the land use planners in Bangladesh.

2. Methodology

2.1 Selection of the study area

Gazipur district under Dhaka division, Bangladesh was selected as the study area. As Gazipur district is at the vicinity of the capital city of Dhaka, there may be significant urbanization trends there. It was hypothesized that the urbanization trends influenced the changes of several land uses, changed the Normalized Difference Vegetation

Index (NDVI) and Land Surface Temperature (LST) over 2000 and 2021. For this reason, Gazipur district was selected for the study (Figure 1).

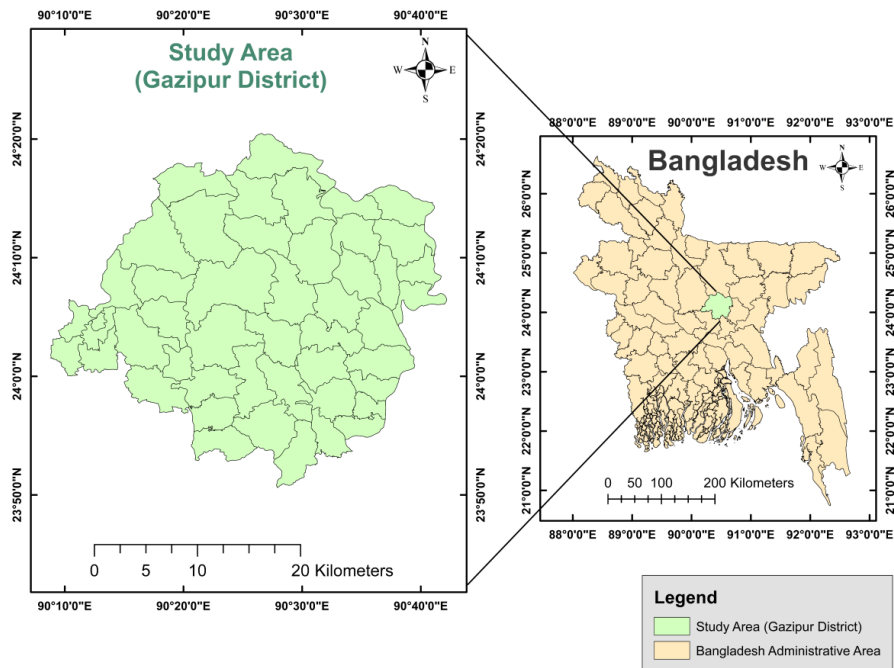


Figure 1. Study area (Gazipur district) in Bangladesh.

2.2 Description of the study area

Gazipur district is located at the north of the capital city of Dhaka, Bangladesh. It is surrounded by the Kishoreganj and Mymensingh districts on the north, the Narsingdi district on the east, the Narayanganj and Dhaka districts on the south, and the Tangail district on the west [25]. The geographic position of the district is between 23°53'N and 24°20'N and between 90°09'E to 90°42'E [25] as shown in the figure 1. The total land of the district is 1806.36 km². Of the total area, 17.53 km² is riverine and 273.42 km² is forested [25]. Annual maximum average temperature is 36°C and minimum average temperature is 12.7°C with annual precipitation 2376 mm [25]. The district comprises 1 city corporation named Gazipur City Corporation, 4 Municipalities named Kaliakair, Tongi, Kaliganj and Sreepur. The district belongs to five upazilas named Gazipur Sadar, Kapasia, Kaliakair, Sreepur and Kaliganj. It comprises of 44 unions, 762 mauzas and 1,114 villages [25]. Different rivers such as old Brahmaputra, Balu, Turag, Shitalakshya, Banar and Bangshi flow through this

district [26]. The total population of the district is 34,03,912 from which males are 17,75,310 and females are 16,28,602, and the ratio of them is 109:100, growth rate is 5.21% per year with population density 1884 km⁻² [25]. There are 31 *Mahallas* and 9 wards in the Gazipur town. With 1,23,531 residents, the town has a 49.32 km² area. There are 2505 people per square kilometer in the district [25].

Oryza sativa, *Brassica nigra*, *Corchorus* sp., *Capsicum frutescens*, *Arum* sp., *Curcuma longa*, *Zingiber officinale*, *Saccharum officinarum* etc. are main crops and *Mangifera indica*, *Litchi chinensis*, *Carica papaya*, *Rubus allegheniensis*, *Artocarpus heterophyllus*, *Ananus comosus*, *Psidium guajava*, *Averrhoa carambola*, *Arecaceae* sp., *Ziziphus mauritiana*, *Carissa carandas*, *Limonia acidissima* and *Tamarindus indica*, etc. are the main fruits of this district [26, 27]. About 42.74% of 538597 holdings are carrying out agricultural activities and produce above mentioned crops and fruits [25]. Some non-farming activities also earn revenues in this district [28]. The physiographic pattern of this area is known as Madhupur Jungle tract (Bhawal Gar), some area covered by low rounded hills and shallow bides (valleys) [29]. *Boro*, *aman*, *aus* are grown largely and jute, *mesta*, mustard, sesame, pineapple, sugarcane, jack fruit are cultivated around all areas of this district except town areas [26]. Around 80% of the Madhupur tract area is covered by coppice sal (*Shorea robusta*), Garjan (*Dipterocarpus turbinatus*) along with Sheel Koroy (*Albizia procera*), Kadam (*Anthocephalus cadamba*), Black Berry (*Syzygium cumini*), etc. [30]. The central canopy comprises of Bahera (*Terminalia bellirica*), Neem (*Azadirachta indica*), Banian tree (*Ficus benghalensis*), Kanchan (*Bauhinia variegata*), Jarul (*Lagerstroemia speciosa*), Sonalu (*Cassia fistula*), Ashwatha (*Ficus religiosa*) Minjiri (*Cassia siamea*), Haritaki (*Terminalia chebula*), Amra (*Spondias mangifera*), Kumbhi (*Careya arborea*), Ajuli (*Dillenia pentagyna*), and Mango (*Mangifera indica*) [30]. The wild animals found in this area are Rhesus monkey (*Macaca mullata*), Hispid hare (*Caprolagus hispidus*), Wild boar (*Sus scrofa*), Jungle cat (*Felis chaus*), South asian porcupine (*Hystrix indica*), Flying fox (*Pteropus giganteus*), Jackal (*Canis aureus*), Fruit bat (*Cynopterus sphinx*), Asian house shrew (*Sorex myosurus*) Common otter (*Lutra perspicillata*), Mongoose (*Herpestes edwardsi*), House mouse (*Mus musculus*), Common house rat (*Bandicota bengalensis*), etc. [31].

2.3 Methods

Remotely sensed satellite imageries were extracted from the Landsat-5 and landsat-8 satellites. Satellite imageries were extracted from the Google Earth Engine (GEE) cloud storage of Landsat collections provided by the United States Geological Survey (USGS). Imageries were filtered by using date filter and cloud cover filter to generate cloud free time specific imageries and reprocessed for Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST) and Land Use and Land

Cover Change (LULC). Inputting the shape file of Gazipur District in Google Earth Engine, JavaScript code for NDVI, LST and LULC during 2000 and 2021 were imposed for the analysis. Time series data from 2000 to 2021 were analyzed for NDVI and LST (Figure 2). Field data was collected by visiting different areas of Gazipur district to trace out the actual situation of those areas. Specifically, spatial data for five LULC classes, i.e., agricultural land, built-up areas, deep forests, light forests, and water bodies were collected during the field survey. These data were used to extract the optical reflectance characteristics of each LULC class, which were then employed for supervised LULC classification and validation.

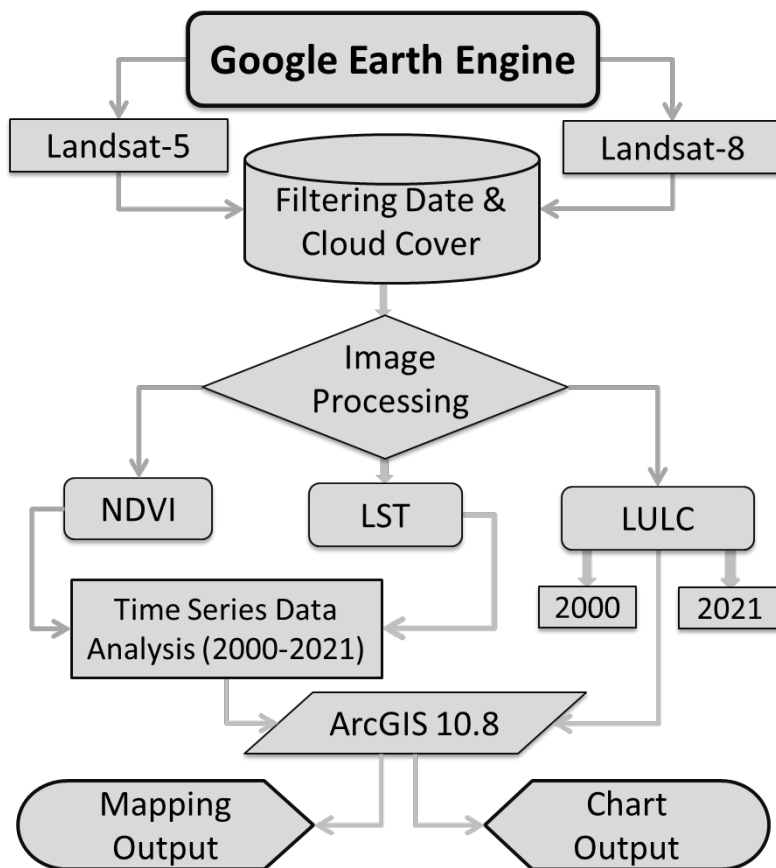


Figure 2. Methodological flowchart of the study.

By using ArcGIS 10.8, extracted map from Google Earth Engine was prepared for final analysis. The scale of the map was maintained as 1:400000.

2.3.1 Land Use and Land Cover (LULC)

In Google Earth Engine, the land use and cover was classified into five categories according to the table below (Table 1).

Table 1. Land use classification in the Gazipur district of Bangladesh.

Land cover types	Description
Agricultural Land	Land applied for agriculture, paddy field, vegetables and fruits, other cultivable land
Built-up Area	All manipulated land, including roads, highway, parks, industrial, residential, commercial, and other infrastructures
Deep Forests	Forests with continuous vegetation and large trees
Light Forests	Homestead garden, forests with scattered vegetation, bush and shrubs
Water Bodies	Permanent water bodies, lakes, pond and reservoirs, ditches, wetlands, inundated low-lying areas, swampy land and aqua fishing.

The LULC areas were identified by training and classifying satellite imagery based on the generated training samples for each land cover category. The samples were divided into two sets, 70% for training and 30% for validation. The Random Forest (RF) algorithm was employed to classify the LULC in the study area using the 70% training set. Validation of the classifier's accuracy was conducted using the 30% validation samples and an error matrix generated in GEE. The overall accuracies of land use classification for 2000 and 2021 were 0.93 and 0.99. While the Kappa statistics of the same years were 0.90 and 0.99. Different colors were assigned for Agricultural Land, Built-up Area, Deep Forests, Light Forests and Water Bodies. The processed map of Land Use and Land Cover was extracted from Google Earth Engine and processed in ArcGIS 10.8 for final mapping. By using land use conversion matrix, areas of different categories were calculated.

2.3.2 Normalized Difference Vegetation Index (NDVI)

NDVI value ranges from -1 to +1. NDVI value between -1 to 0 represent inanimate object and near 1 represent very healthy vegetation and vice-versa.

It is applied for quantifying greenness of vegetation, vegetation density, changes in vegetation health. And it is calculated as a ratio between the red (R) and near infrared (NIR) values as seen in the formula (i), (ii) and (iii) : [32, 33]

$$NDVI = \frac{NIR - Red}{NIR + Red} \text{ --- (i)}$$

In Landsat 5, [34, 35]

$$NDVI = \frac{Band4 - Band3}{Band4 + Band3} \text{ --- (ii)}$$

In Landsat 8, [36]

$$NDVI = \frac{Band5 - Band4}{Band5 + Band4} \text{ --- (iii)}$$

2.3.3 Land Surface Temperature (LST)

Imageries of Landsat 5 TM, following formula, (iv) to (vii), were used: [37, 38]

a. Conversion of Digital Number to Radiance

$$L_{\lambda} = Grescale \cdot QCAL + Brescale \text{ --- (iv)}$$

Which is also expressed as

$$L_{\lambda} = \left(\frac{LMAX_{\lambda} - LMIN_{\lambda}}{QCALMAX - QCALMIN} \right) (QCAL - QCALMIN) + LMIN_{\lambda} \text{ --- (v)}$$

Here,

L_{λ} = Spectral radiance at the sensor's aperture of satellite (Watts/ (m²*sr*))

Grescale = Rescaled gain (the data product "gain" carried in ancillary data record or product header of Level one) in (Watts/(m² x sr x μm))/DN

QAL = Calculated calibration value of pixel (in DN)

$LMIN_{\lambda}$ = Spectral radiance scaled to QCALMIN in (Watts/ (m² x sr))

$LMAX_{\lambda}$ = Spectral radiance scaled to QCALMAX in (Watts/ (m² sr))

QCALMIN = Minimum quantized calibrated pixel value (corresponding to $LMIN_{\lambda}$) in DN

= 1 for level 1 Product Generation System (LPGS)

= 1 for National Land Archive Product System (NLAPS)
[processed after 04/04/2004]

= 0 for NLAPS [Products processed before 04/05/2004]

$QCALMAX$ = Maximum quantized calibrated pixel value (corresponding to $LMAX_\lambda$) in DN

= 255

b. Radiance to Reflectance

$$\rho_p = \frac{\pi L_\lambda d^2}{ESUN_\lambda \cos \theta_s} \text{---(vi)}$$

ρ_p = Unitless planetary reflectance

π = Mathematical constant approximately equal to 3.14159

L_λ = Spectral radiance at the sensor's aperture

d = Earth-Sun distance in astronomical units interpolated from values

$ESUN_\lambda$ = Mean solar exo-atmospheric irradiances

θ_s = Solar zenith angle in degrees

c. Spectral Radiance into TOA Brightness Temperature (in Kelvin)

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \text{---(vii)}$$

Here,

T = Effective at-satellite temperature in Kelvin

K_2 = Calibration constant 2

K_1 = Calibration constant 1

L_λ = Spectral radiance in (Watts/ (m²*sr*))

d. Conversion of degree Kelvin into degree Celsius

$C = T - 273.15$

C = temperature in degree Celsius

The LMINs and LMAXs are corresponding of how data products of the output Landsat ETM+ Level 1 are scaled in radiance units. The LMIN represents to the radiance at the minimum quantized and calibrated data DN (QCALMIN), which is typically "1" or "0" and LMAX represents the radiance at the maximum quantized and calibrated data DN (QCALMAX), typically "255".

For Landsat 8 TM imageries, the formula, (viii) to (xi), mentioned below were used: [39, 40]

- a. Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) at Sensor Spectral Radiance:

Images were operated in absolute radiance unit using 32-bit floating point calculations. The values were converted to 16-bit integer values in the finishing Level 1 product. With the use of the radiance scaling factors provided in the metadata file, they can then be converted to spectral radiance.

$$L_{\lambda} = ML * Q_{cal} + A_L - - - - - (viii)$$

Where:

L_{λ} = Spectral radiance (W/(m² * sr * μ m))

ML = Radiance multiplicative scaling factor for the band
(RADIANCE_MULT_BAND_n from the metadata)

A_L = Radiance additive scaling factor for the band
(RADIANCE_ADD_BAND_n from the metadata)

Q_{cal} = Level 1 pixel value in DN

- b. Operational Land Imager (OLI) TOP of Atmosphere Reflectance:

The sixteen-bit integer values in product of the Level can also be transformed to reflectance TOA, similarly to the conversion to radiance. The Level 1 DN readings are converted to reflectance of TOA using the equation below.

$$\rho'_{\lambda} = M_{\rho} * Q_{cal} + A_{\rho} - - - - - (ix)$$

Where

ρ'_{λ} = planetary Spectral Reflectance of TOA, without taking the solar angle into account (without unit)

M_{ρ} = multiplicative scaling factor for the band of Reflectance
(REFLECTANCEW_MULT_BAND_n of the metadata)

Q_{cal} = Level 1 value of pixel (in DN)

A_{ρ} = scaling factor for the band of Reflectance additive
(REFLECTANCE_ADD_BAND_N of the metadata).

Note that: ρ'_{λ} is not true TOA Reflectance, since the solar elevation angle is not corrected for in TOA Planetary Spectral Reflectance. On the users' request, this correction factor is not included in the Level 1 scale; while some users like to compute their own per-pixel solar elevation angle throughout the scene, others are

happy with the scene-center solar elevation angle provided in the metadata. After selecting a solar elevation angle, the conversion to actual

c. TOA Reflectance:

$$\rho_{\lambda} = \frac{\rho'_{\lambda}}{\cos(\theta_{SZ})} = \frac{\rho'_{\lambda}}{\sin(\theta_{SE})} \text{---(x)}$$

ρ_{λ} = planetary reflectance of TOA

θ_{SE} = sun elevation angle at local; the metadata contains the scene center sun elevation angle expressed in degrees.

θ_{SZ} = solar top angle at local; $\theta_{SZ} = 90^{\circ} - \theta_{SE}$

d. Thermal Infrared Sensor (TIRS) Top of Atmosphere Brightness Temperature

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_{\lambda}} + 1\right)} \text{---(xi)}$$

Where:

T = Top of atmospheric brightness temp. in Kelvin (K) where:

L_{λ} = TOA spectral radiance (Watts/ (m² * srad * μ m))

K_1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)

K_2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

3. Results and Discussion

3.1 LULC for 2000 and 2021

Land use was classified into five categories i.e. deep forests, light forests, water body, agricultural land and built-up area to estimate land use and land cover (LULC) change of Gazipur district. Among all the land uses in the Gazipur District, maximum agricultural land was found in the Sreepur Upazila followed by Gazipur Sadar in 2000 (Figure 3). From all the parts of the district, agricultural land was decreased from 2000 to 2021, but along the bank of Shitalakshya River in Kapasia, it slightly increased in the same time frame. Among all the landuses, total amount of agricultural land had decreased in the district from 2000 to 2021. Built-up area were increased mostly in the western parts of Gazipur i.e. Gazipur sadar, Kaliakair and Sreepur. But it was decreased in Kapasia and Kaliganj.

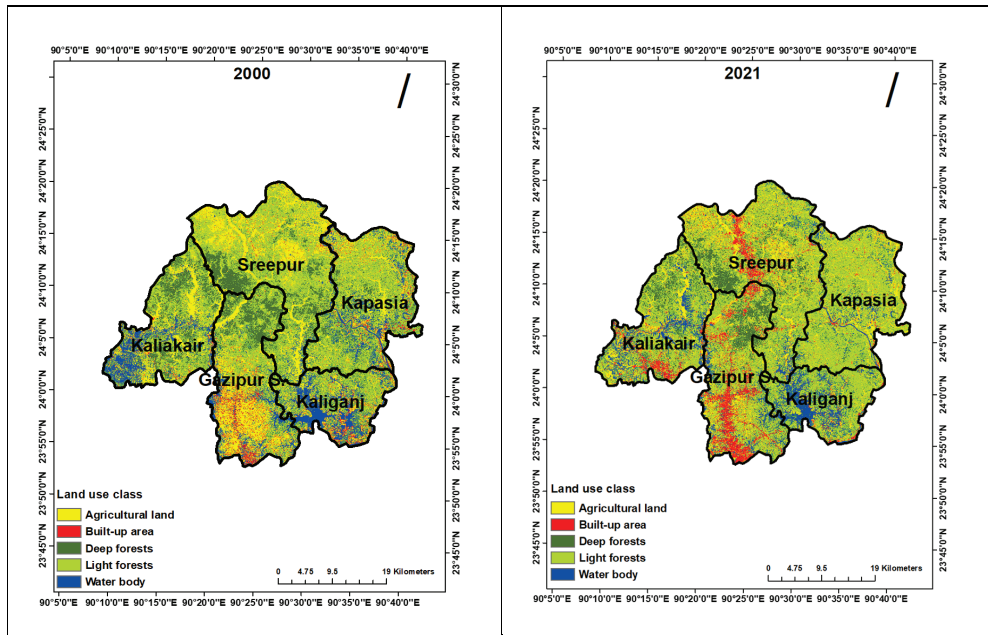


Figure 3. Land use class distribution in Gazipur district of Bangladesh.

Deep forest area decreased all over the district. The decreasing rate was high in Kapasia and Kaliganj Upazila, moderate in Kaliakair and Gazipur Sadar and low in Sreepur. Light forest area was increased in all areas except Sreepur.

Land use distributions were estimated based on upazila sections. It was found that deep forest area was reduced in all the Upazila from 24076 ha to 16858 ha during 2000 to 2021 (Table 2). Among all the land uses, deep forests were 14.48% in 2000 and it reduced to 10.13% in 2021. Light forests area was increased in four upazilas and reduced only in Sreepur.

Table 2. Land use distribution in the Upazila of Gazipur district of Bangladesh.

Landuse Upazila	Deep forests		Light forests		Water body		Agricultural land		Built-up area	
	2000	2021	2000	2021	2000	2021	2000	2021	2000	2021
Gazipur Sadar	5280	3917	10427	13015	4817	4351	11014	7109	2998	6144
Kaliakair	6134	3801	10727	12486	6002	5422	6749	6393	858	2368
Kaliganj	1103	500	6575	9995	7001	6084	3936	2545	1321	812
Kapasia	3999	1527	16715	21838	5653	3323	7249	7318	1544	1156
Sreepur	7559	7112	22246	21164	2060	2805	13526	11716	880	3474
Total	24076	16858	66689	78498	25533	21985	42475	35080	7602	13954

Total light forest area was increased by 11809 ha from 2000 to 2021. In 2000, light forest area was 40% and it was increased up to 47.18% in 2021. Area of water bodies decreased alarmingly in four Upazilas but increased in Sreepur only. Total area of water bodies decreased by 3548 ha. Water body was 15.35% in 2000 and it became 13.21% in 2021. Agricultural land was decreased in Gazipur sadar, Kaliakair, Kaliganj and Sreepur but increased in Kapasia only. It was 25.54% in 2000 and 21.1% in 2021. So overall agricultural land was decreased by 7395 ha.

The changes in built-up areas across Gazipur district from 2000 to 2021 reveal a fascinating trend of urban sprawl. The built-up area increased largely in Gazipur sadar, Kaliakair and Sreepur but decreased in Kaliganj and Kapasia in comparison with the corresponding area in 2000. Sreepur stands out with a surprising increase of 294.8%, Kaliakair also saw significant expansion, growing by 176.0% (Figure 4). These rapid changes are particularly noticeable in comparing with the less growth of Gazipur Sadar, the district's central hub, which saw a 104.9% increase of built-up between the studied periods, perhaps because it has already experienced substantial development before. On the other hand, Kaliganj and Kapasia showed reverse trend, with built-up areas shrinking by 38.5% and 25.1%, respectively. This decline might reflect a move away from urbanization, possibly as land is repurposed for other uses or due to shifts in the local economy.

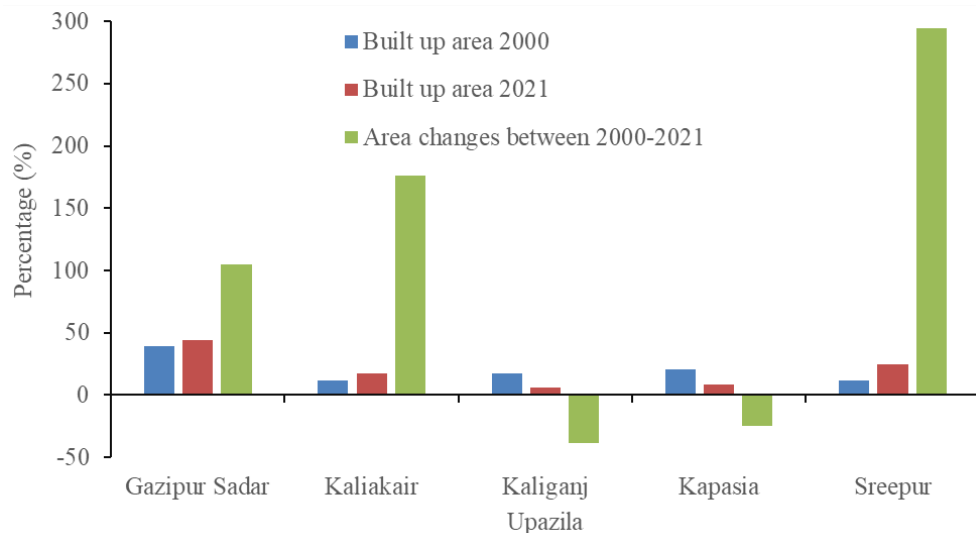


Figure 4. Trend of built-up area changes between 2000 and 2021 due to urbanization in different upazila of Gazipur district in Bangladesh.

During the study period, built-up area extensively spread out over time. Deep vegetation, water bodies abruptly decreased over the study period. The pattern of changing the land use and land cover is similar to studies of Vani and Prasad [1], Imran et al. [12], Dewan and Yamaguchi [13], Imran et al. [14], Jalayer et al. [41], Babalola and Akinsanola [42], Hussain et al. [43] i.e. vegetated area was 70.043% in Nigeria which decreased to 10.127%, built-up area increased by 190.16% in Dhaka, Bangladesh from 1975 to 2003, vegetation cover was decreased from 91.6% in 2000 to 89.3% in 2020 and urbanization was increased by 4.5% at Okara, Panjab, Pakistan, built up area increased by 204% from 1993 to 2020 Chittagong City, Bangladesh, built-up area was increased by 67% from 1993 to 2020 converting the water bodies, bare land and vegetation cover in Dhaka City, Bangladesh, forest cover will continue to decrease from 29.46 % (50720.2667 ha) in 2021 to 25.67 % of area (44207.78694 ha) in 2040 (predicted), built-up area was increased from 28.20 km² in 1990 to 138.01 km² in 2018 in Vijayawada city of Andhra Pradesh state, India respectively. In case of water bodies, it was decreased.

This declining pattern is similar to the studies of Vani and Prasad [1], Dewan and Yamaguchi [13], Jalayer et al. [41] i.e. water bodies decreased by 31.09%, in Chalus, Iran, 13.61% water bodies decreased from 2000 to 2021 water bodies decreased from 87.82 km² in 1990 to 33.72 km² in 2018. In Gazipur, agricultural land decreased by 17.41% during the study period and it also follows the studies of Dewan and Yamaguchi [13], Jalayer et al. [41] i.e. 70.32% agricultural land decreased in Dhaka during 1975 to 2003, 301.5% decreased in Chalus, Iran from 2001 to 2021. Light forest area was increased in Gazipur during the study period similar to the study of Rafa et al. [15] i.e. deep vegetation area expanded from 0.086 km² to 7.56 km² (21.8% increased) from, medium vegetation area expanded from 7.8 km² to 17.31 km² (27% increased) from 1995 to 2000 and From 2015 to 2020, sparse vegetation expanded from 20.24 km² to 26.06 km² (16.9% increased) at Sitakunda Botanical Garden and Ecopark in Chattogram, Bangladesh.

Agricultural land was decreased by 8170 ha from 2000 to 2021. The area was 42591 ha in 2000 and 34421 ha in 2021. Built-up area was 7125 ha in 2000 and 13660 ha in 2021. So this area was increased by 6535 ha. Deep forest area was 36764 ha in 2000 and it declined to 29952 ha in 2021 by decreasing 6812 ha.

Total light forest area was 68351 ha in 2000 and 80422 ha in 2021. It was increased by 12071 ha. Water bodies became 21764 ha from 25387 ha from 2000 to 2021. It was decreased by 3623. So agricultural area was decreased by 19.18%, deep forest area was decreased by 18.53% and water bodies were decreased by 14.27%. Built-up area and light forest area were increased by 91.72% and 17.66%, respectively. So the rate of increasing built-up area was maximum and the rate of decreasing agricultural area was maximum.

3.2 NDVI for 2000 and 2021

Normalized Difference Vegetation Index (NDVI) values were classified into six categories i.e. -0.229 to 0.015, 0.015 to 0.140, 0.140 to 0.180, 0.180 to 0.270, 0.270 to 0.360 and 0.360 to 0.930 showed in figure 5. NDVI values -1 to 0 represents water, snow, clouds, 0 to 0.2 represents barren land, built-up area and rocks and 0.2 to 1 represents vegetation [44]. The map showed that NDVI value increased slightly over the study period.

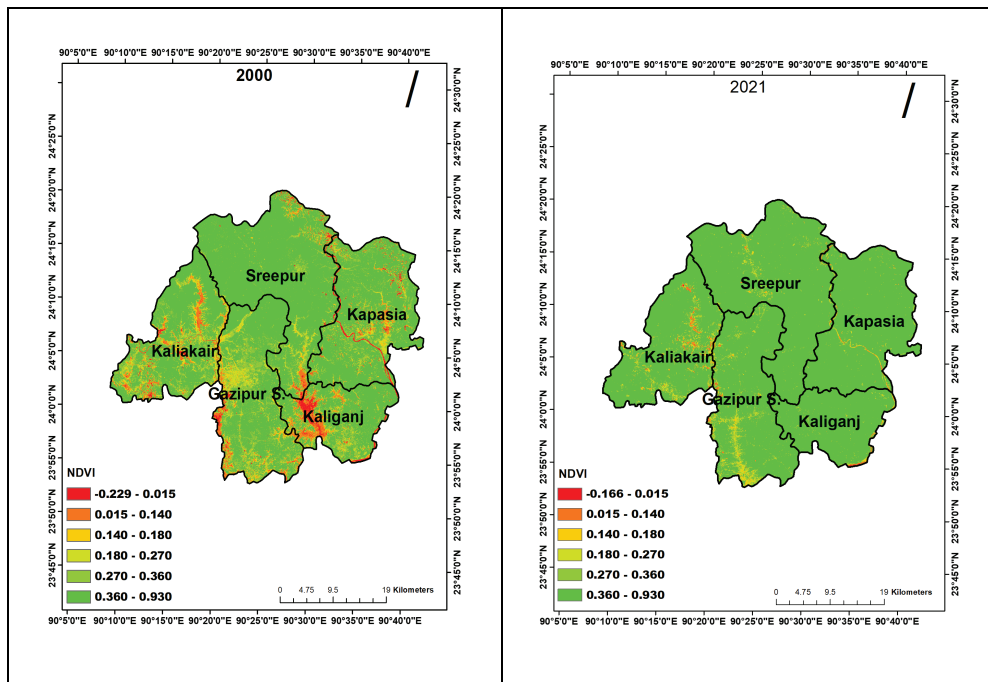


Figure 5. NDVI map of 2000 and 2021 in Gazipur district, Bangladesh.

Most of the areas having negative NDVI values in 2000 were converted into the areas having NDVI values above 0 in 2021. It referred that water bodies were decreased. In LULC analysis above, it was mentioned that water bodies were decreased by 3538 ha from 2000 to 2021 and it was 15.35% in 2000 and 13.21% in 2021. The maps showed that water bodies and deep forest area were decreased but light forest area and agricultural land were increased.

Among the minimum values of NDVI in all the Upazilas, Kaliakair had the lowest value i.e. -0.229 and Kaliganj had the highest value i.e. -0.185 in 2000 (Table 3). And maximum values were about same in all the Upazilas of the district. Mean NDVI was

found maximum in Sreepur and minimum in Kaliganj, i.e. 0.431 and 0.363, respectively, in 2000.

Table 3. Normalized Difference Vegetation Index (NDVI) in Gazipur district of Bangladesh between 2000 and 2021.

Upazila	NDVI-2000				NDVI-2021			
	MIN	MAX	MEAN	STD	MIN	MAX	MEAN	STD
Gazipur Sadar	-0.224	0.669	0.366	0.121	-0.057	0.800	0.506	0.125
Kaliakair	-0.229	0.665	0.374	0.137	-0.148	0.802	0.534	0.138
Kaliganj	-0.185	0.691	0.363	0.174	-0.025	0.771	0.537	0.094
Kapasias	-0.221	0.691	0.403	0.135	-0.010	0.799	0.571	0.088
Sreepur	-0.223	0.666	0.431	0.103	-0.166	0.793	0.576	0.090

In 2021, minimum values of NDVI were decreased but maximum and mean values of all Upazilas were increased. Among the minimum values, lowest NDVI value was -0.148 and highest value was -0.010 in 2021. Maximum NDVI values were about same in all areas i.e. tends to 0.800. Highest mean value was found in Sreepur that was 0.576 and lowest mean value was found in Gazipur Sadar that was 0.506 in 2021. Standard deviation was found maximum in Kaliakair and minimum in Kapasias i.e 0.138 and 0.088 respectively in 2021.

Figure 6 showed the trend line of NDVI values from 2000 to 2021. Each year represented average NDVI value of all months of that year. In 2000, NDVI value was near to 0.350. But in 2001, it decreased to near 0.310. Then up to 2006, average NDVI increased to about 0.390 uniformly. Again from 2007 to 2009, average NDVI value decreased. It was drastically increased from 2010 to 2013 but declined to trendline in 2014 and continued up to 2019. From 2019 to 2021, NDVI values were slightly decreased. But overall increasing was reached to 0.576.

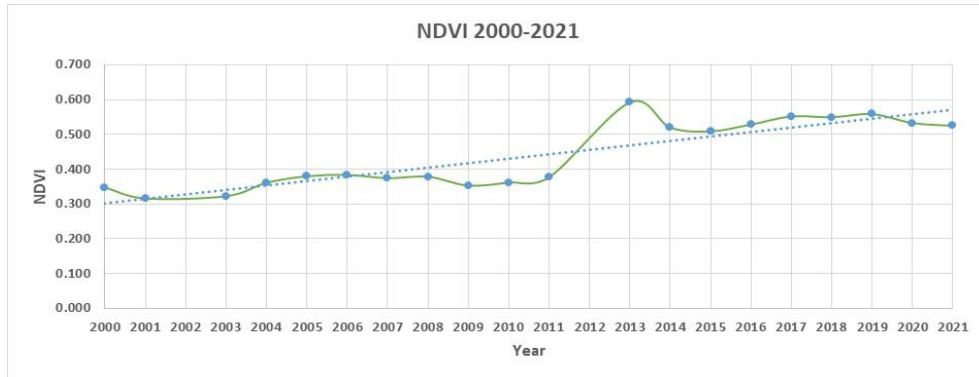


Figure 6. Average Normalized Difference Vegetation Index (NDVI) in Gazipur district, Bangladesh from 2000 to 2021.

Although there were ups and downs in NDVI values year after year, average NDVI values were increased day by day. Five years i.e. 2009, 2010, 2011, 2012, 2013 were derailed from the trend line that was slightly decreased followed by drastically increased.

Similar to this study, Tucker et al. [45]; [15], Nath [17], Babalola and Akinsanola [42] also conducted the NDVI analysis and found that NDVI increased by 9% from 1982 to 1991, decreased by 5% from 1991 to 1992, and increased by 8% from 1992 to 1999 at 45°N to 75°N; NDVI values declined due to reduced vegetation area from 70.043% to 10.127% at Nigeria from 1984 to 2013; forest cover decreased by 15.47% from 1989 to 2010 due to different natural and manmade causes in Bandarban Hill Tracts, Bangladesh; deep vegetation area expanded from 0.086 km² to 7.56 km² (21.8% increased) from 1995 to 2000, medium vegetation area expanded from 7.8 km² to 17.31 km² (27% increased) from 1995 to 2000, sparse vegetation expanded from 20.24 km² to 26.06 km² (16.9% increased) from 2015 to 2020, respectively. And most of the deep and medium vegetation areas were converted to scattered vegetation area, respectively [15].

3.3 LST for 2000 and 2021

Average Land Surface Temperature (LST) of Gazipur district, Bangladesh for 2000 and 2021 were showed in the figure 7. Areas of Gazipur district were classified into 5 temperature zones. Those were 21.37-22.92°C, 22.93-24.36°C, 24.37-25.69°C, 25.70-27.17°C and 27.18-28.95°C for 2000 and 22.31-22.92°C, 22.93-24.36°C, 24.37-25.69°C, 25.70-27.17°C, 27.18-28.95°C for 2021. Average lowest temperature was 21.37°C in 2000 and it was increased to 22.31°C in 2021. That is, the average minimum temperature of these 21 years had increased by about 1°C.

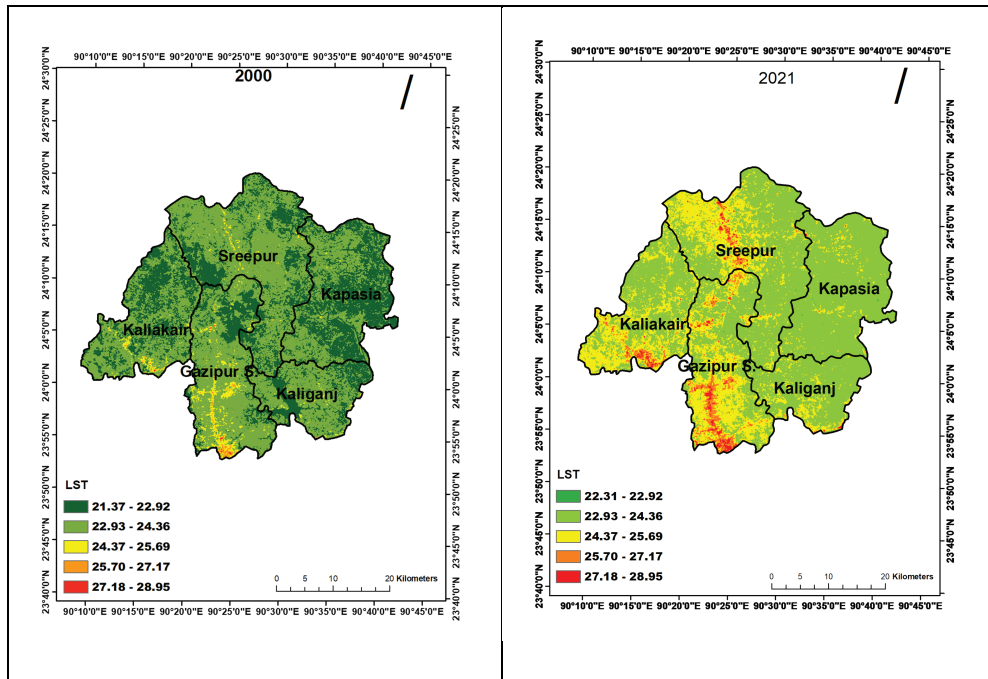


Figure 7. Land Surface Temperature (LST) in Gazipur district in Bangladesh between 2000 and 2021.

Average maximum temperature was 27.18-28.95°C in 2000 and it remained same in 2021. But it is clear in the map that, most of the areas belonging lower temperature in 2000 were converted into higher temperature zone in 2021. Most of the areas belonging 21.37-22.92°C temperature in 2000 were turned into the areas of higher temperature in 2021. Same phenomenon was happened in case of the areas having 22.93-24.36°C. In the maps (Figure 7), the areas of belonging 24.37-25.69°C temperature in 2021 were several times greater than that of 2000. The areas of 25.70-27.17°C and 27.18-28.95°C temperature in 2021 was several times greater than the same temperature zone of 2000. That means, the areas having temperature below 25.70-27.17°C and 27.18-28.95°C, were turned into the areas having those temperature. Although, temperature did not increase much, areas of low temperature within the boundary became areas of high temperature which indicated light forest and impervious surface i.e. urbanization by converting the deep forests area and water bodies.

Minimum, maximum, mean and standard deviation of LST for all upazilas of the district were tabulated in the table 4. In 2000, lowest average minimum temperature

was found in Kapasia i.e 21.37°C and highest average minimum temperature was found in Kaliganj that was 21.78°C.

Table 4. Land Surface Temperature (LST) in Gazipur district of Bangladesh between 2000 and 2021.

Upazila	LST (°C)-2000				LST(°C)-2021			
	MIN	MAX	MEAN	STD	MIN	MAX	MEAN	STD
Gazipur Sadar	21.42	29.96	23.58	0.75	22.68	32.87	24.67	0.95
Kaliakair	21.61	28.05	23.16	0.53	22.96	31.47	24.40	0.65
Kaliganj	21.78	28.93	23.18	0.47	22.31	29.93	24.04	0.47
Kapasia	21.37	27.23	22.96	0.40	22.47	28.58	23.81	0.34
Sreepur	21.62	27.25	23.20	0.45	22.60	31.06	24.25	0.65

Among all the maximum LSTs, the lowest value was found in Gazipur sadar 29.96°C and the highest values were in Kapasia 27.23°C in 2000. Mean LST were found minimum in Kapasia 22.96°C and maximum in Gazipur sadar 23.58°C in 2000. The lowest standard deviation of LST was found in Kapasia i.e. 0.40°C and the highest value was found in Gazipur sadar i.e. 0.75°C. In 2021, LST was increased in all areas of the district. Minimum LST were increased by 1.26°C in Gazipur sadar, 1.35°C in Kaliakair, 0.53°C in Kaliganj, 1.1°C in Kapasia and 0.98°C in Sreepur. Maximum LST were increased by 2.91°C in Gazipur sadar, 3.42°C in Kaliakair, 1°C in Kaliganj, 1.35°C in Kapasia and 3.81°C in Sreepur from 2000 to 2021. Mean LST were increased by 1.09°C in Gazipur sadar, 1.24°C in Kaliakair, 0.84°C in Kaliganj, 0.85°C in Kapasia and 1.05°C in Sreepur from 2000 to 2021.

Gradually increasing the LST in the study area from 2000 to 2021 was showed in the trend line (Figure 8). The each point above the years in the trend line indicated the average LST of related year below the point.

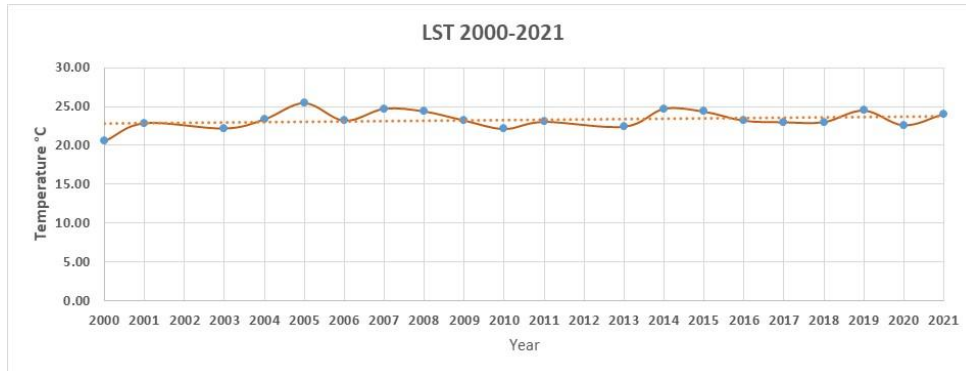


Figure 8. Average Land Surface Temperature (LST) in Gazipur district of Bangladesh from 2000 to 2021.

Trend line started from around 23°C in 2000 and it increased to 24°C in 2021. LST was around 21°C in 2000 and it increased largely after five years. But it was slightly decreased in 2006. After successive two years, i.e. 2007 to 2008, LST was increased. From 2009 to 2013, LST decreased slightly. Again LST was increased up to 25°C in 2014 and 2015. Although LST decreased in 2017, 2018 and 2020, the values were remained close to the trend line. It reached to 24°C in 2021. Overall, the LST increased throughout the study period in Gazipur district.

The pattern of increasing the LST is similar to some studies following. LST was increased by 0.62°C from 2001 to 2020 in Bogura, Bangladesh [19]. In Dudpukuria-Dhopachari Wildlife Sanctuary, Bangladesh, LST was increased by 7.7°C from 1990 to 2020 [20]. Winter and summer LSTs were increased by 0.15°C and 0.24°C per year from 1993 to 2020 in Chattogram City, Bangladesh [12]. LST was increased by 0.24°C per year from 1993 to 2020 in Dhaka City, Bangladesh [14] and LST was increased by 0.28°C per year from 1995 to 2015 in Beijing, China [46].

3.4 Rapid urbanization accelerates the LST

The figure 9 reveals a strong relationship between built-up area changes and temperature increases in different places of Gazipur district. The Upazila with ample urban expansion, such as Sreepur (295%) and Kaliakair (176%), showed the highest rises in maximum LST, 3.8°C and 3.4°C, respectively. This finding suggested that rapid urbanization is contributing to a local increase in temperatures, likely due to the urban heat island effect. On the other hand, Upazila like Kaliganj and Kapasia, where built-up areas declined, show minimal temperature changes.

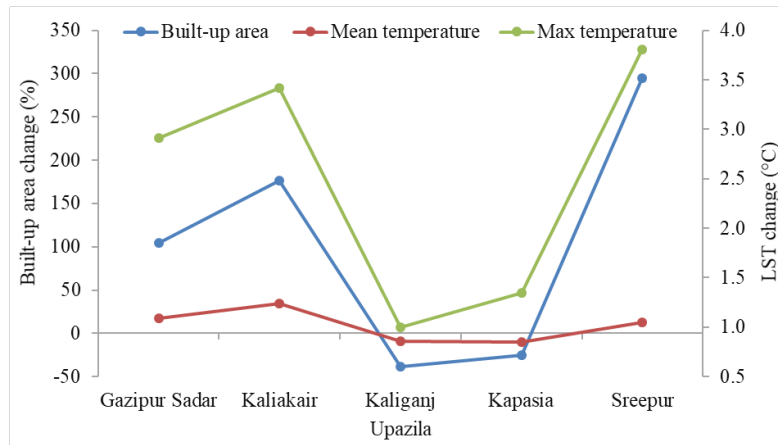


Figure 9. Relationship with the built-up area changes and the land surface temperature changes in different Upazila of Gazipur district of Bangladesh.

The correlation values further support the positive relationship between the built-up and temperature, with a moderate correlation of 0.72 between built-up area and mean temperature, and a very strong correlation of 0.98 between built-up area and maximum temperature. These findings of our study highlight the significant impact of urban sprawl on temperature extremes, emphasizing the importance of incorporating climate considerations into urban and city planning, particularly the growing city to mitigate the rising heat levels in fast-developing regions like Gazipur in Bangladesh.

4. Conclusion

The trend of urbanization is increasing rapidly in many sub-urban areas of Bangladesh. To understand this changing trend, the present study identified the changes in Land Use and Land Cover (LULC), Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) in Gazipur District. Five major LULC classes were identified, where deep forest area was decreased by 7218 ha, water bodies were decreased by 3584 ha and agricultural land was decreased by 7395 ha from 2000 to 2021. And light forest area and built-up area increased by 11809 ha and 6352 ha, respectively, from 2000 to 2021. The 2001-2008 and 2011-2021 were the distinct periods of increasing the NDVI values but in the years of 2009, 2010 and 2020, it was decreased slightly. Overall, average NDVI was increased from 0.350 to 0.576 during the study period from 2000 to 2021. Average minimum LST, average maximum LST and average mean LST were increased by 1.044°C, 2.498°C, and 1.014°C from 2000 to 2021. And most of the lower LST belonging areas were

converted to higher LST zones making the land surface more impervious. Finally, it is commented that urbanization in Gazipur district changed the LULC from environmentally friendly to environmentally degraded state. It also increased the LST in the most parts of the Gazipur district. The novelty of this study is an understanding that within 2000 and 2021, Gazipur district lost deep forest, water bodies and agricultural land. The study underscores the significant relationship between rising urban temperatures and rapid urban expansion, driven by the conversion of natural land cover such as water bodies, agricultural land, and forests. The finding also highlight that newly urbanized areas are particularly vulnerable to temperature increases, exacerbating the urban heat island effect. Based on the findings, the study emphasizes the importance of incorporating climate considerations into urban and city planning, particularly in rapidly growing cities like Gazipur in Bangladesh. By prioritizing sustainable development practices and preserving green spaces, city planners can help mitigate the adverse thermal impacts of urbanization and promote a more resilient urban environment. The results proved the hypothesis of this study. The findings of the study will be useful to the environmental practitioners of Bangladesh.

Conflict of Interest: *The authors declare that they have no conflict of interest.*

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